THE

AMERICAN REPERTORY

OF

ARTS, SCIENCES, AND USEFUL LITERATURE.

VOL. II. OCTOBER, 1831. No. 10.

OPTICS.

DEFINITION.—Optics is that branch of philosophy which treats of the nature and properties of light.

NATURE AND SOURCE OF LIGHT.—Concerning the nature and source of light, much has been written, without producing any certainty upon the subject: some have considered light as a substance emanating from the sun; others as a fluid like electricity; and others consider it merely as a principle, and attribute to it a sort of pressure, or vibration, propagated from the luminous body through a subtile ethereal medium. The ancients believed light to be propagated from all luminous bodies instantaneously; but it is now proved, that, like any projectile, it employs time to pass through space. It requires about 8¼ minutes for light to come from the sun, consequently it moves at the rate of about 200,000 miles per second. If light consists of particles of matter they must be inconceivably minute, or with such a velocity, they would destroy the eye. This, and many other reasons, have induced many modern philosophers, among whom are our own sagacious Franklin and the celebrated Euler, to adopt the theory of a subtle elastic fluid, not visible when at rest, but by its vibrations affecting the fine sense of the eye, as vibrations of the air affect the ear. Either of these theories will solve the various phenomena of light; and it is therefore better to content ourselves with examining its known properties, than to pursue an investigation that will only lead us into a labyrinth of speculation.

Velocity.

The greater portion of light we derive in some manner through the instrumentality of the sun: such

Solar light. light is called solar light, and is not simple, or of one kind, but is a mixture or composition of many lights, differing from each other in colour and refrangibility, which is their tendency to turn from a direct course when made to pass through transparent mediums.

Homogeneous light. Light which cannot be separated into differently coloured and differently refrangible rays, is called homogeneous light. It is a rule in optics that the intensity of light decreases as the square of the distance

Intensity of light. increases; that is, at twice the distance you will have but one fourth as much light; at three times the distance you will have but one ninth as much light, and so on.

Chemical properties. Solar light is capable of producing powerful chemical changes, altering the colour of many substances, causing some gases to unite and sometimes to explode, igniting some substances, and giving to flowers their colours. Even animals require the presence of the rays of the sun, and their colours seem materially to depend upon the chemical influence of these rays. The light of the moon, and the light produced by combustion, do not always produce the same chemical effects as solar light. By the observations of Ritter and Wollaston, it would appear that most of the chemical effects are produced, not by the rays that excite heat or light, but by certain rays which, from their effects, are termed chemical rays: near and within the violet part of a ray is found the greatest chemical power.

History.—The property of light which received the earliest attention, was its propagation in rectilinear lines: next to this was probably the law of reflection. The equality of the angles of incidence and of reflection was taught in the Platonic school, and probably earlier. Aristotle devoted considerable attention to the phenomena of rainbows, halos, &c. and in a treatise on optics, in the works of Euclid, some of the properties of concave and convex mirrors are mentioned. Refraction does not appear to have been discovered until a later period; in the time of Aristophanes burning refractors are described; and it was not until the first Christian century that Seneca discovered the magnifying power of convex mediums, and the various colours produced by a prism. In the second century, Claudius Ptolemy, of Alexandria, observed with precision the various phenomena of refraction, and the aberration of light. From this time no advances were made in the science

until the beginning of the twelfth century, when some steps were taken to improve the theory of vision. In the thirteenth century, Roger Bacon devoted much attention to the study of optics, and appears to have been so well acquainted with lenses and their combinations, that he must in all probability have known

Microscope. the principles upon which the microscope and telescope are constructed. In the sixteenth century Maurolycus explained the structure and functions of the eye; and Baptista Porta, of Naples, invented the

Camera obscura. camera obscura. In this and the following century, considerable approximation was made by Fleschier, Antonio de Dominis, Montucla, Kepler and Hariot, towards the true knowledge of the phenomena of the

Rainbow. rainbow. Galileo, Snellius, Descartes, Bartolinus, Huygens, Grimaldi and Newton, in the seventeenth century improved the telescope, discovered the law of refraction, the polarization of light, the difference of colour and of refrangibility, and the inflection or diffraction of light. It is difficult to assign a precise date to the invention of the telescope: Bacon was acquainted with its principles; Metius, Jansen, and Lapprey, are said to be its first constructors; and Galileo and Kepler, first applied it to astronomy.

OPTICAL DEFINITIONS.

Ray.—By a ray is meant the motion of a single particle of light, which is always in a right line; or a ray is the least possible quantity of light that can be intercepted or transmitted.

Pencil of rays, is any parcel of rays proceeding from a single point.

Medium, is any pellucid or transparent body which suffers light to pass through it.

Parallel rays, are such as move always at the same distance from each other.

Divergent rays, are such as continually recede from each other.

Convergent rays, are such as continually approach each other.

Focus, is a point at which converging rays meet.

Imaginary focus, is a point towards which rays tend, but which they are prevented from reaching by some intercepting substance.

Refraction, is the tendency which rays have, when passing from one medium into another of different density, to bend from their former course, and thus to make an angle with their previous line of direction.

Reflection, is the tendency which rays have, when striking against certain surfaces, to be thrown back without penetrating into the substance.

Incident rays, are those which fall upon surfaces from luminous bodies.

Angle of Incidence.—When a ray does not fall perpendicularly, the angle, which is contained between a line perpendicular to the reflecting surface and the line in which the ray falls, is called the angle of incidence.

Angle of Reflection, is the angle contained between a line perpendicular to the surface, and the line in which the ray is reflected.

Angle of Refraction, is the angle contained between the refracted ray, and a line perpendicular to the refracting surface.

Mirror or Speculum, is an opaque body, smooth and polished, so that it will reflect rays, and by this means form images of bodies that are placed before it.

Plane mirrors, are those whose surfaces are perfectly flat.

Convex mirrors, are those whose surfaces swell out more prominent than their edges.

Concave mirrors, are those whose surfaces sink in with a hollowness.

Lenses, are glasses of a circular form, either convex or concave.

Plano-convex, has one side flat and the other convex.

Plano-concave, has one side flat and the other concave.

Double convex, is convex on both sides.

Double concave, is concave on both sides.

Mensicus, is convex on one side and concave on the other.

Axis, is a line passing through the centre of a lens.

Luminous bodies, are those that shine by their own light.

Transparent bodies, are such as admit light to pass through them.

Opaque bodies, are all such as are not luminous nor transparent.

Spectrum.—When a ray is divided into its separate colours, the surface on which the separated rays fall, and which they colour each with their own peculiar light, is called a spectrum.

Dispersion, is the separation of the various kinds of light that compose a solar beam.

Caustic curves, luminous intersections, formed by two setts of rays reflected upon the same point of a surface, and causing it to appear lighter than the surrounding parts.

Aberration of light, the difference of position between the focus of rays that are near the axis of a medium with a spherical surface, and those that are distant from it.

Polarization of light, that property by which a ray of common light, when it is made to pass through some crystals, especially Iceland spar, becomes divided into two rays or beams, having poles or sides of different properties; but the right hand side of one will have the same properties as the left hand side of the other.

Double Refraction, the division of the ray as above.

Newton reduced the knowledge of the science,

which had been acquired before his time, into the following axioms:

Axiom 1.—The angles of reflection and refraction lie in one and the same plane with the angle of incidence.

Axiom 2.—The angle of incidence is equal to the angle of reflection.

Axiom 3.—If the refracted ray be turned directly back to the point of incidence, it shall be refracted into the line before described by the incident ray.

Axiom 4.—Refraction out of the rarer medium into the denser, is made towards the perpendicular—that is, so that the angle of refraction becomes less than the angle of incidence.

Axiom 5.—The sine of the angle of incidence is in a given ratio to the sine of the angle of refraction.

Axiom 6.—Homogeneal rays which flow from several points of any object, and fall perpendicularly on any reflecting or refracting plane or spherical surface, shall afterwards diverge from so many other points, or be parallel to so many other lines, or converge to so many other points as they at first proceeded from: and this whether they be refracted or reflected once, or more than once from different surfaces.

Axiom 7.—Wherever the rays, which have come from all the points of any object, meet again after being made to converge or diverge by reflection or refraction, there they will form a picture of the object upon any white body upon which they happen to fall.

Axiom 8.—An object seen by reflection or refraction, appears in that place from whence the rays, after their last refraction or reflection, diverge in falling on the spectator's eye.

Newton's own work upon optics opens with the announcement that "lights which differ in colour, differ also in refrangibility."

Divisions.—Since the time of Newton the science of optics has usually been considered under four heads, viz. Catoptrics, which treats of reflection: Dioptrics, which treats of refraction; Chromatics, which treats of colours; and Perspective, which gives rules for the formation of pictures upon a plane surface, so as to represent the objects of nature. But before these divisions are considered, it may not be amiss to mention some facts which cannot be well introduced into either branch of the subject.

Mode of Vision.—All luminous bodies are seen by the light which comes directly from the body to the eye; but all non-luminous bodies are seen by light which comes to

them from some luminous body, or from some non-luminous body that had previously received it.

Emission of Light.—Light is emitted from every visible point of a luminous or an illuminated body, and proceeds in every direction, as radii from the centre of a sphere.

Shadows.—As light moves in straight lines, whenever it meets with a non-transparent body it is stopped in its course, producing darkness on the opposite side, and if this darkness falls on any object it will form a shadow. This shadow is not always perfectly dark, because it may happen that light from some other body falls upon the same space occupied by the shadow: the more intense the light the darker will be the shadow. If the luminous body be larger than the opaque, the shadow will gradually diminish until it terminates in a point; but if the luminous body be the smallest, the shadow will continue to increase indefinitely; the rate of increase or decrease is proportioned to the nearness of the two objects: if the two bodies were of the same size, the shadow would not be changed either way.

Catoptrics.—This division of optics explains the properties of reflected light, particularly that which is reflected from mirrors. Of mirrors there are three kinds, plane, convex, and concave.

Plane Mirrors.—The properties of plane mirrors may be expressed in the following aphorisms:

Place of Image.—The image will appear as far behind the mirror as the object is before it.

Size.—The image will appear of the same size, and in the same position as the object; and any object may be reflected, that is not more than twice the length and breadth of the mirror.

Number.—If the object be an opaque body, and its rays fall on the mirror nearly in direct lines, there will be only one image visible, which will be reflected by the inner surface of the glass. But if the object be a luminous body, and its rays fall very obliquely on the mirror, there will appear, to an eye placed in a proper position, several images; the first of which, reflected from the outer surface of the glass, will not be so bright as the second, reflected from the inner surface. The other images, which are produced by the repeated reflections between the two surfaces of the glass, will be in proportion less vivid, to the number of eight or ten, when they will be scarcely visible.

Convex Mirrors.—These likewise have the following general properties.

Place of Image.—The image will always appear behind the mirror. Parallel rays, falling on the mirror, will have the focus or image at half the distance of the centre from the mirror. The centre of a convex or concave mirror is an imaginary point, which would be the centre of the sphere of which a convex mirror forms a part of the outside, and a concave mirror a part of the inside: the centre of a convex mirror is always behind it, and the centre of a concave mirror always before it, and this centre recedes in distance from the mirror in proportion as the surface of the mirror approaches to flatness. Converging rays, falling on a convex mirror, must proceed from an object at half the distance of the centre before it, in order to appear at that distance behind it. Diverging rays will have their image at less than half the distance from the centre: if the object be placed in the centre of the mirror, its image will appear at one eighth of that distance behind it.

Centre of Mirrors.

Size.—The image will be less than the object, but it will appear in the same position.

Shape.—It will be curved, but not as the mirror, spherical.

Concave Mirrors.—At the centre of a concave mirror, the image will appear of the same size as the object.

Appearance of Image.—Parallel rays will have their focus at one half the distance of the centre. Converging rays will form an image before the mirror. In diverging rays, if the object be at less than one half the distance of the centre, the image will be behind the mirror, erect, curved, and magnified; but if the distance of the object be greater, the image will be before the mirror, inverted and diminished.

Sun's Rays.—The sun's rays, being parallel, will be collected into a focus at half the distance of the centre, where their heat will be augmented in proportion as the surface of the mirror exceeds that of the focal spot.

Reflected Light.—If a luminous body be placed in the focus, its reflected rays, being parallel, will strongly enlighten a space of the same dimensions of the mirror, at a great distance. If the luminous body be placed nearer than the focus, the rays will diverge, and consequently will enlighten a much larger space. It is on this principle that reverberators are constructed.

Dioptrics.—Dioptrics is that branch of optics which treats of the properties of refracted light; that is, of light which enters transparent bodies, and is transmitted through their substance.

Law of Refraction.—If a ray of light enter any transparent sub-

stances, such as water, oil, glass, air, &c. in a direction perpendicular to the surface, it will continue on in a direct course; but if it enter in an oblique direction, it will be bent or refracted from its course, and will take a new direction. If it goes from a rarer medium into a denser one, as from air into water, it will be bent nearer to a perpendicular to the surface; and on the contrary, if from a denser to a rarer, as from glass to water, it will be bent further from the perpendicular. It is this property of light which produces the appearance of a break, or crook, in a stick that is partly immersed in the water in a slanting direction; and hence all objects under the water are not seen in their true place by an eye that is out of the water. The refractive power of bodies seems in some measure to depend upon the inflammability of their ingredients.

Prism.—If a ray of light pass through a prism, it will suffer two refractions, and will come out as much in the downward direction as it entered in the upward, and *vice versa*. In cases of refracted light, there is always some portion absorbed or reflected, while the larger part is transmitted; but if a ray of light strikes the second or opposite surface of a prism, in a *very oblique* direction, it will all of it be *reflected*, and none transmitted.

Planes.—If parallel rays of light fall upon a plane glass, they will suffer two refractions, which will just counterbalance each other, and the rays will leave the glass in a line parallel to, though not the same as that in which they entered. Diverging rays are made to diverge at a still greater angle, but the distance of their diverging point is made less. Converging rays are made to converge at a less angle, but the distance of the point of convergency is increased. Two surfaces, equally curved, one concave and the other convex, like a watch-glass, will act upon light nearly like plane glass; that is, parallel rays will retain their parallelism: therefore one of these kinds of glasses, with parallel surfaces, must be used whenever we wish to have the objects seen through them retain their form and position.

Sphere.—If parallel rays fall upon a transparent sphere, they will suffer two refractions, and will be made to converge to a point at a little distance from the opposite side of the sphere. If the rays are converging, they will come to a point at a less distance from the sphere; and if they are diverging, they will find their focus at a greater distance.

Convex Lenses.—Parallel rays will be refracted, in passing through

convex lens, upon the same principles as in passing through spheres, with this exception, that there will be but one ray suffering no refraction in the lens; whereas several may pass through a sphere without refraction; because a lens, having but one axis, can have but one ray parallel to its axis, or perpendicular to its surface, but a sphere has several axes. The point at which parallel rays find their focus, in a double convex lens, is equal to the radius of the sphere of which the lens forms a part; but if the lens be plano-convex, the focal distance will be equal to the diameter of the sphere. When the rays reach the focal point towards which they converge, they will cross the middle or unrefracted ray, and diverge from the focal point; and if another lens, of the same convexity, be placed at the same distance from the focus, it will refract them so that they will proceed in a parallel manner; and the same effect will take place, when a luminous body, whose rays diverge, is put in the focal point of a lens. If a candle is put nearer than the focal point, the rays will diverge after passing the glass, but in a less degree than before; if the object be placed further than the focal point, the rays will converge to a point more distant than the focus, and form an inverted image of the object, which will be more remote from the glass in proportion as the object is near to it, and the image will be large in proportion as it is distant. Converging rays will be collected to a point nearer than the principal focus. Whenever rays converge, they will form an inverted image of the object from which they proceed, but if they are rendered parallel, no image is formed. All the heat as well as the light of the sun's rays, is collected into the focus, and it will be rendered as much greater than the heat of common light, as the surface of the lens is greater than that of the focus. If we wish to have the image appear more bright, we must either illuminate the object, or increase the size of the lens. If the image is received at the focal point, upon white paper, or any smooth white surface, it will appear inverted; but if we hold another glass between the focal point of the first glass and the eye, we shall see an *image* of the *image*, which will be *inverted* as it regards the first image, but *erect* as it regards the object; thus by using two glasses, or by inverting the object, we may obtain an erect image.

Focus of a convex lens.

Inverted image.

Heat of focus.

Erect image.

Concave Lenses.—If parallel rays pass through a concave lens, they

will be refracted so as to proceed as if they had come in right lines from a diverging point in the focal centre of the lens. If the lens be plano-concave, the rays will proceed as from a point at double that distance. If diverging rays fall upon a double concave, they will be refracted as if they had come from a radiant point more remote than the principal focus, but nearer than the real diverging point. Converging rays will be made to diverge, as if they had come from a radiant point, as far from the lens on the side to which they are incident, as the point towards which they originally converged is from the opposite side.

Mensicus.—The general effect of a mensicus, in refracting parallel, diverging, or converging rays, is the same as that of a convex lens of the same focal length.

Concavo-Convex, is the same as that of a concave lens of the same focal distance.

Images of objects being produced in focal points only by converging rays, we must use a *convex lens*, if we wish to obtain an image by *refraction*; but a *concave mirror* will produce the same effect by *reflection*.

Aberration of Light.—All transparent mediums, having spherical surfaces, give images that are not perfectly distinct; because only those rays which are near the axis are sent to precisely the same focal point; the rays, which proceed through those parts of the medium remote from the axis, having different focal points around the principal one; and thereby serving in a slight degree to spread some of the rays proceeding from the object. But this defect may in a great measure be remedied, by having glasses so arranged that their aberrations shall counteract each other.

Dispersion of Light.—Light is not only refracted in whole rays by a transparent medium, but it is also separated, or dispersed, into the elementary kinds of light which compose a solar ray: the angle of dispersion, like that of refraction, differs in different substances, and also differs in the same substance from the angle of refraction. This leads us to the consideration of

CHROMATICS, or PHYSICAL OPTICS, which treats of the physical properties of light, as exhibited in the decomposition and recomposition of white light; in its decomposition by absorption; in its inflexion or diffraction; in the colours of thick and thin plates; and in the double refraction and polarization of light.

Solar Light.—A beam of solar light is composed of seven different

kinds, viz: red, orange, yellow, green, blue, indigo, and violet. If a room is entirely darkened, except a small hole in one shutter, and a prism placed in the hole, a ray from the sun will be decomposed, and will form a spectrum on the wall, or on a screen, consisting of the colours already named; the red being the lowest, the orange next, then the yellow, the green, the blue, the indigo, and the violet uppermost. No lines are seen on the spectrum dividing the colours, but they melt by imperceptible gradations into each other. Supposing the spectrum to be divided into 360 parts; the red will have 45, the orange 27, the yellow 40, the green 60, the blue 60, the indigo 48, and the violet 80. The colours of the spectrum are not equally brilliant, the ends are the faintest, while the deepest yellow and lightest green contain the most light. The greatest quantity of heat is usually found near or within the red ray; but by the use of different refractors, it may be found in the yellow and orange

Primary colours.

Secondary colours.—Secondary colours are those made by the mixture of some of the primary colours; white is formed by the mixture of all the colours; black is the absence of all colours.

Decomposition by absorption.—The effect of coloured glasses, and fluids, in decomposing light by absorbing it, was not known to Newton; and modern philosophers, who have decomposed light by this means, admit but three primary colours, viz: red, yellow, and blue.

Inflexion of Light.—If a ray of light is received into a darkened room, through an aperture in the shutter, and an opaque body is held between the aperture and the opposite wall, the shadow produced on the wall is found to be increased by fringes of differently coloured lights.

Colours of Fibres and Grooves.—Mother-of-pearl, and many other very finely grooved and fibred surfaces, when viewed under a reflected light, exhibit all the colours of the rainbow; and the same property may be communicated to wax, and other similar substances, by impression.

Theory of Fits.—Newton, finding that light was under some circumstances reflected from plates of glass and other transparent substances, instead of being refracted, accounted for it by supposing that each particle of light was a sphere turning on its axis, and that one pole had a refracting, and the other a reflecting tendency; consequently every particle would be transmitted or reflected, according to the nature of the

pole which touched the surface of the plate. This theory was called the 'theory of fits of transmission and of reflection.'

Absorption of Light.—All bodies, even the most transparent, absorb some of the light which they receive, and neither transmit, nor reflect the whole of it. The portion thus absorbed seems to be lost in the body; at least no trace of its presence can be found. Some bodies absorb one kind of colour, while other bodies reject this and absorb other kinds. The colour which any body presents to our eyes, is that kind of colour, or combination of colours, which the body reflects; all other colours it either absorbs or transmits.

OPTICAL PHENOMENA.

Unusual Refraction.—The atmosphere is a refracting medium, whose density gradually increases towards the surface of the earth; hence rays of light, while passing through it, suffer continual refraction, and are bent into a curve line. The density of the atmosphere is affected by cold and heat, which operates, not only at different times and places, but also at the same time and over the same place, in the successive strata of air, there being currents of air of different temperatures passing over and under each other. As every change of density will produce a change of refraction, curious appearances are frequently produced by this means, which are referred to the power of unusual refraction. Of this nature is the looming of objects seen over the surface of the sea; the erect and inverted images of ships seen in the air over vessels sailing at a distance, and the pictures of mountains, castles, villages, &c. seen above, beyond, or nearer than the objects themselves. These appearances never continue long, and a change in the relative position of the objects and the spectator's eye will cause them to disappear. The appearance called mirage, whereby the sand of burning deserts assumes the appearance of water when shone upon by the sun, is attributed to the unusual refraction which the rays suffer when reflected from the burning sand. The celebrated *fata morgana*, which is seen in the straits of Messina, is a phenomenon of this kind. A spectator, on a hill in Reggio, with his back to the sun, and his face to the sea, at the time in the forenoon when the sun is about mid-way to the zenith, sees, upon the sea of Reggio, pilasters, arches, castles, columns, towns, palaces, villages and trees, plains with herds and flocks, armies of men on foot

Images on sea.

Mirage.

Fata morgana.

and horseback, and in fact, every object which can send rays of light to be reflected from the surface of the water: these appearances, in certain states of the atmosphere, can also be seen in the air, although less vividly. In explanation of the phenomena occasioned by unusual refraction, it may be said, that as the atmosphere differs in density, rays of light, in passing through it, will be bent into curved lines; and as all images of objects are seen in that direction from which the ray seemed to come when entering the eye, an image, in these cases, is seen in the direction of a tangent to that end of the curve which touches the eye.

RAINBOWS.—These luminous arches are usually seen single, but under favourable circumstances, two are sometimes seen, the inner and outer, or primary and secondary. The primary rainbow consists of seven different bows coloured according to the seven primary colours, the red being the outermost. This bow is the union, in a circular form, of a great number of prismatic spectra; and is produced by the transmission of light through a great number of transparent spherical drops of rain. If we look into a globe of glass, or water, opposite the sun, we shall see a prismatic spectrum reflected from the farther side of the globe.

Primary Rainbow.—This is produced by two refractions and one intermediate reflection of a ray of light. If a sunbeam fall upon a drop of rain, those rays which pass through or near the axis of the drop will be reflected to a focus behind the drop and will not meet the eye; but those which fall upon the upper side of the drop, will be refracted, the red rays least, and the violet most, and will fall upon the back of the drop with sufficient obliquity to cause many of them to be reflected, at the same angle, to the lower side of the drop, where they will suffer another refraction, which will carry them to the spectator's eye.

Secondary Rainbow.—This is formed outside the primary, with its colours reversed, and has a breadth nearly twice as great as the primary, but its colours are much fainter in consequence of the light having suffered one more reflection than in the primary; for the secondary is produced by two refractions and two reflections. If a beam of light falls upon the under side of a drop, it will be refracted to the opposite part of the under side, from whence it will be reflected to the upper part of the back side; another reflection will bring it

to the upper part of the side on which it first entered, from whence it will be carried by another refraction to the spectator's eye.

Supernumerary Rainbows.—Within the primary rainbow are sometimes seen two or three other bows of less brightness as they recede from the primary.

Lunar Rainbows.—These are sometimes seen, but the colours, being produced by reflected light, are scarcely visible.

Fog-bows.—These occasionally appear, and resemble a nebulous arch, in which the colours are invisible.

Red rainbows, distorted rainbows, and inverted rainbows on the grass, are sometimes seen. These latter are formed by the drops of rain suspended on the spiders' webs in the fields.

Halos.—When the sun and moon are seen in a clear sky they exhibit no change of colour, and have no attendant phenomena. In other conditions of the atmosphere, the two luminaries not only experience a change of colour, but are surrounded with a variety of luminous circles of various sizes and forms. When the air is charged with dry exhalations, the sun sometimes appears as red as blood; when seen through watery vapours, he is shorn of his beams, but preserves his disk white and colourless. When light fleecy clouds pass over the sun and moon, they are often encircled with one, two, three, or even more coloured wings, like those of thin plates; and in cold weather, when particles of ice are floating in the high regions, the two luminaries are frequently surrounded with the most complicated phenomena, consisting of concentric circles, circles passing through their discs, segments of circles, and mock suns formed at the points where these circles intersect each other. The name *halo* is given indiscriminately to these phenomena, whether they are seen round the sun or the moon. They are called *parhelia* when seen round the sun, and *paraselenæ* when seen round the moon. The small halos seen round the sun and moon in fine weather are frequently called coronæ. Newton considers these rings as formed by the light passing through very small drops of water; and the rings will increase in size as the globules become less. The production of halos may be illustrated experimentally by crystallizing various salts upon plates of glass, and looking through the plates at the sun or a candle.

Watery vapours.

Parhelia.

Paraselenæ.

Coronæ.

Diverging Beams.—This phenomenon is of frequent occurrence in summer, when the sun is near the horizon, and arises

from a portion of the sun's rays passing through openings in the clouds, while the adjacent portions are obstructed by the clouds; this produces the appearance of rays shooting from the sun.

Converging Beams.—This phenomenon is of much rarer occurrence than the other, and when it is seen, the rays appear to converge to a point as far below the horizon, as the sun is above it. This appearance is always seen opposite the sun, and generally at the same time with the diverging beams; as if another sun diametrically opposite the real one, were below the horizon throwing upwards his divergent beams.

THE EYE.—The body of the eye is of a spherical form, having three membranous coverings; the external one is called

Sclerotica. the sclerotica, commonly known under the name of the white of the eye; it has a projection in that part of the eye which is exposed to view, which is called

Cornea. the transparent cornea, because, when dried, it has nearly the consistence of very fine horn, and is sufficiently transparent for the light to obtain a free passage through it.

The second membrane which lines the cornea, and

Choroid. envelopes the eye, is called the choroid; this has an opening in front, just beneath the cornea, which forms

Pupil. the pupil or sight of the eye, through which the rays of light pass into the eye. The pupil is surrounded

Iris. by a coloured border called the iris, which by its muscular motion, always preserves the pupil in a circular form, whether it is expanded in the dark, or contracted by a strong light.

The third and last membrane of the eye, is called

Retina. the retina. This is a fine and delicate membrane, formed by the expansion of the optic nerve, and of the most perfect whiteness; this nerve proceeds from the brain, enters the eye at the side next the nose, and is finely spread over the interior surface of the choroid. The retina serves to receive the images of objects produced by the refraction of the different humours of the eye, and painted as it were upon its surface.

The coats of the eye which invest and support each other after the manner of the concentric coats of an onion, enclose three transparent bodies, called the aqueous, crystalline, and vitreous humours.

Aqueous humour.—The aqueous humour, so called from its liquidity and its resemblance to water, occupies the space immediately behind the cornea.

Crystalline Humour.—Beyond this, is situated the crystalline humour, so called from its clearness and transparency; it has the form of a lens, and refracts the rays of light in a greater degree of perfection, than any that have been constructed by art; it is attached by two muscles to each side of the choroid. The back part of the eye, between the crystalline humour and the retina, is filled by the vitreous humour, which derives its name from a resemblance it is supposed to bear to glass or vitrified substances.

Vitreous humour.

Orbit.—The cavity in which the eye rests is called the orbit, which is lined with fat to facilitate the motions of the eye.

Eye-lids.—These protect and cover the eye, and by peculiar secreting organs, diffuse a fluid over it which cleans and polishes it.

Mode of Vision.—The rays of light, coming from an object, fall upon the eye, and proceeding through the pupil, are refracted by the several humours, and unite in a focus on the retina, where they form an inverted image of the object; the sensation excited by this image, is conveyed by the optic nerve to the brain. This may be illustrated by taking a bullock's eye while it is fresh: cutting off the three coats from the back part quite to the vitreous humour, and putting a piece of white paper over that part, and holding the eye towards any bright object, when an inverted image will be seen upon the paper. The whole body of rays which come from any object, may converge towards the eye; but each particular point of an object sends divergent rays, which, if there were no humours in the eye to refract them, would be spread indistinctly on the surface of the retina, without forming an image; thus the humours operate like lenses in refracting light to a focus. If an object is brought too near, the rays from it will enter the eye with too much divergency, and will not be refracted to a focus before they reach the retina; consequently an indistinct image will be formed. If an object is too far distant, the rays will come to a focus before they reach the retina, and an indistinct image will be formed. But we are enabled to overcome these apparent difficulties by the use of muscles, which either alter the convexity of the crystalline humour, or by moving it forward or backward, adjust its focus to the retina. Sometimes the crystalline humour is either too much or too little convex, so that the muscular power is not sufficient to adjust it, in which cases spectacles are

necessary to render the rays more or less diverging.

Inverted Vision.—The images of all objects are represented on the retina in an inverted position; but the objects do not appear inverted to us, because by habit we are accustomed to find the upper part of an object in that direction from which the rays come that are on the lower part of the retina; we also see all objects and parts of objects, in that direction from which the rays come; consequently as the rays from the bottom of an object come from downwards, they excite in our minds the idea of the lower part of the object although they touch the upper part of the retina.

Single Image.—When both eyes are directed with their axes alike, towards an object, there will be but one image perceived, because the same parts of each image fall upon each retina, and each optic nerve is similarly affected: but if both eyes have not precisely the same direction, the object will appear double, as is the case with cross-sighted persons.

Image not *object seen.*—It must be remembered that we do not see objects themselves, but their images which are painted on the retina. Many proofs might be adduced, but one is sufficient; the real size of an object we know never varies, but an object that is at a distance appears smaller than when it is near, consequently we do not see the object, but its image, which would be made smaller by the withdrawal of the object which produced it.

Angle of Vision.—The angle under which we see any object, or the opening between the two rays that proceed from each extremity, is called the angle of vision; and it is the size of this angle which determines our ideas of the size of the object from which the rays proceed. The object seen is supposed to be in the circumference, and the eye in the centre of a circle, of which the two rays from each extremity, are two radii, converging from the object to the eye. If the object is removed, and thereby the radii become prolonged, they must be brought nearer together in order to preserve their ends at the same distance apart; this will make the angle between them less, and will render the object apparently smaller: thus the size of the image depends upon the distance of the object. The most accurate eyes cannot perceive objects whose extreme rays do not subtend angles of more than two seconds of a circle; and most eyes cannot distinguish objects whose angle is less than a minute. If a body is in

motion at so slow a rate as to go through less than twenty degrees in an hour, its motion will be imperceptible; and this will be the case, however great the velocity of the body may be, provided its distance reduces the angle of its motion to less than twenty degrees.

SPECTACLES.—It has been explained before, that if objects are seen through a perfectly flat glass, the rays of light pass through it, from them to the eye, in a straight direction and parallel to each other, causing the objects to appear very little diminished or enlarged, or nearer or farther off, than to the naked eye; but if the glass they are seen through has any degree of convexity, the rays of light are directed towards the centre in an angle proportional to the convexity of the glass, and meet in a point, at a greater or less distance from the glass, as it is more or less convex. The point where the rays meet is called the focus, which is nearer or farther off, according to the convexity of the glass. Its magnifying power is also in proportion to its convexity; for as a flat glass scarce magnifies at all, the less a glass departs from flatness, the less it magnifies; and the more it approaches to a globular figure, the nearer its focus is, and the more its magnifying power.

People's different length of sight depends on the same principle, and arises from a more or less convexity of the cornea and crystalline humour of the eye; the rounder they are, the nearer will the focus or point of meeting rays be. The case of short-sighted people is only an over roundness of the eye, causing a very near focus; and that of old people is a sinking or flattening of the eye, whereby the focus is thrown to a great distance. The remedy for the last is a convex glass, to supply the want of convexity in the eye itself; whereas a concave glass is needful for the first, to scatter the rays, and prevent their coming to a point too soon.

Oldness.—If either the cornea or crystalline humour, or both of them, be too flat, their focus will not be on the retina, where it should be to render the vision distinct, but beyond the eye. The rays therefore passing from an object through the humours of the eye, are not converged enough to unite on the retina; and the observer can have but a very indistinct view of the object. A convex glass, of a proper focus, placed before the eye, remedies this, causing the rays to converge sooner, and imprinting the image duly on the retina.

Near-sightedness.—The cornea or crystalline humour, or both, being

too convex, the rays entering in from an object converge to a focus in the vitreous humour, and diverging from thence to the retina form a very confused image thereon. A concave glass before the eye remedies this inconvenience, causing the rays to diverge between it and the eye, and lengthening the focal distance, so that if the glass be properly chosen, the rays will unite on the retina, and form a distinct picture of the object.

Shape of *Spectacles.*—The frames of spectacles should not be straight, so that both eyes may be in the same plane; but so bent in the middle, that the axes of both glasses may be directed to one point, at such a distance as you generally look with spectacles. By this means the eyes will fall perpendicular upon both glasses, and make the object appear distinct; but if they fall obliquely upon the glasses, it will cause a confused appearance in the object.

Burning Glasses.—Every lens, whether convex or plano-convex, will collect, by refraction, the rays of the sun dispersed over its surface into a point, and thus become a burning lens.

As all the rays which fall upon the lens, are united in its focus, their effect ought to be so much the more, as the surface of the lens exceeds that of the focus. Thus, if a lens four inches broad collect the sun's rays into a focus at the distance of one foot, the image will not be more than one tenth of an inch broad. The surface of this little circle is 1600 times less than the surface of the lens, and consequently the sun's rays must be as many times denser within that circle; it is not therefore surprising that it burns with a degree of ardour and violence exceeding any culinary fire. By means of a burning glass, a piece of wood may be charred or burned to a coal in a decanter of water, and yet the sides of the decanter, through which the rays pass so very near the focus, will not be cracked, nor in any way affected; nor will the water be in the least degree warmed. If the wood be taken out, and the rays thrown on the water, no continuance of collected rays in this way, will either heat the water or crack the glass; but if a piece of metal be put into the water, it soon becomes too hot to be touched, and communicating its heat to the water, makes it not only warm, but sometimes causes it to boil. Though water alone will not be affected, yet if a little ink be thrown into it, the water will soon be heated.

Micrometer.—The new micrometer is a stage (on which the objects are placed) moveable by a fine screw, which has a hand or small index passing over the divisions of a graduated circle: a fine threaded screw is the essential part in all micrometers of the best or most perfect kind. This screw was formerly placed in the focus of the eye-glass, just where the image is formed: but this method being attended with some difficulties, the screw is here applied to the stage, or rather to the object itself; which being attended with no difficulty, will render the use of it more general and pleasant. The upper part of the microscope, containing the glass, has a fine wire in its focus, and to it any part of the image may be applied; or the wire applied to any part of the image, by a proper construction of the microscope for that purpose. The object is then placed in a proper manner on the stage, and the screw turned till the image of the object has passed its whole length or breadth under the wire, and then the quantity of its dimension will be known. The number of threads on the screw in one inch is fifty, and the number of divisions on the circular plate, twenty. Therefore one thread, or one turn of the screw, measures one fiftieth part of an inch, and one division of the plate is one twentieth of one fiftieth; that is, one thousandth part of an inch. So that such a micrometer will very exactly measure any small object, or its smaller parts, to the thousandth part of an inch.

Multiplying Glass.—The multiplying glass is made by grinding down the round side of a convex glass, into several flat surfaces. An object seen through this glass does not appear magnified, but appears multiplied into as many different objects as the glass contains plane surfaces. For the rays flowing from the object to all parts of the glass, and each plane surface refracting these rays to the eye, the same object will appear to the eye in the direction of the rays which enter it through each surface.

Magnifying Power.—The magnifying power in all optical instruments depends upon this one principle, that every object is apparently greater or less, in proportion as it is nearer to or farther from the eye; because the nearer it is, the larger is the visual angle under which it appears, and vice versa.

The eye is so formed as to admit of distinct vision by such rays only as are nearly parallel; every object must therefore be removed to such a distance from the

eye, that the rays of light issuing from every point thereof, may fall upon the eye with small divergency or nearly parallel; which distance is found by trial, to be in different eyes, from six to eight inches. Now a convex glass converges parallel rays to a focus; therefore, if an object be placed in the focus of such a lens, the rays proceeding from each point are refracted parallel to the eye and produce distinct vision of that object in its focus. Hence it follows that if a very small object be placed in the focus of a glass whose focal distance is one inch, the eye applied to the lens will have a distinct vision thereof. And this being at a distance six, seven, or eight times nearer than the eye alone could clearly see it, it must appear so many times larger, than to the naked eye.

Magnifying Proportions.—All surfaces are magnified in proportion to the squares of their length or sides; therefore the surfaces of objects are magnified thirty-six, forty nine, or sixty-four times, by a lens of one inch focal distance; also the bulk or magnitude of the whole body will be magnified in proportion to the cubes of the sides or length; and all solid bodies will, by such a lens, be magnified 216, 343, or 512 times respectively. If the lens were but of half an inch focal distance the length of the objects would be magnified twice as much; the surfaces four times, and the magnitude or bulk eight times as much as before.

If the lens be so small that its focal distance is but one-tenth of an inch, the length of an object is magnified 60, 70, or 80 times; the surface 3,600, 3,900, or 6,400 times: and the solidity or whole bulk 216,000, 348,000, or 512,000 times, or so much larger do the bodies of mites, or their eggs, appear than to the naked eye at six, seven, or eight inches distance.

The image is as much larger than the object, as its distance from the lens exceeds the distance of the object from the lens.

Single Microscope.—This consists simply of a convex lens, commonly called a magnifying glass; in the focus of which the object is placed, and through which it is viewed; by this means, the eye may be placed very near to the object; for the lens, by diminishing the divergency of the rays, before they enter the pupil of the eye, makes them fall parallel on the crystalline humour by which they are refracted to a focus on the retina.

Double Microscope.—In a double microscope the object itself is not seen, but a magnified image of it. In this, two lenses

are employed; the one for the purpose of magnifying the object is called the object glass; the other acts on the principle of the single microscope, and is called the eye-glass.

Solar Microscope.—There is another kind of microscope called the solar microscope, which is the most wonderful, from its great magnifying power, and which can only be used when the sun shines, and in a chamber darkened for the purpose. It is composed of a tube, a looking glass, a convex lens, and a single microscope. The sun's rays, being directed by the looking-glass through the tube, and refracted by the convex lens into a focus, in or near which the object is placed, the rays proceed onward, and pass through the single microscope, whereby the image is magnified and thrown upon a screen on the opposite wall. The size of the image will be increased in proportion to the distance of the screen, but its brilliancy will be lessened if the distance is too great. A louse may be made to appear six feet long. There are several conveniences attending this microscope which no other one can possess; the weakest eyes may use it without fatigue; several people can have a view at the same time; and any person can take a correct drawing of any object, by placing a large piece of paper on the screen, and tracing the image thrown upon it.

There are several other varieties of microscopes, but they are all different applications of the same principles which have been illustrated in the description of the three principal kinds.

Refracting Telescope.—In a refracting telescope, the glass which is nearest the object in viewing it, is called the object glass; and that which is nearest the eye is called the eye-glass. The object glass must be convex, but the eye-glass may be either convex or concave. In looking through a telescope the eye is generally in the focus of the eye-glass; but this is not necessary, for the rays will come parallel in either case; but the nearer the eye is to the end of the telescope, the larger will be the field of view. This telescope inverts the image, so that an additional glass would be necessary in viewing terrestrial objects, but no inversion of heavenly bodies takes place because they are round. The magnifying power of this telescope is in proportion as the focal distance of the object glass exceeds that of the eye-glass. Telescopes, in general, represent objects to be nearer, but not larger, when ap-

plied to terrestrial things; thus a man at the distance of a hundred yards, will appear of the common size, but at the distance of only one yard, if viewed through a telescope whose magnifying power is one hundred: but celestial objects will appear both nearer and larger.

Reflecting Telescope.—A telescope of this kind, measuring six feet in length, will magnify as much as a refracting one of one hundred feet in length, and they are now used almost entirely in preference to the refractors. They are constructed after the following manner; in the end of a large tube next to the object, is placed a small concave mirror with its back to the object; the rays from any distant object, passing by this mirror, fall upon the surface of a large concave mirror placed opposite the small one at the other end of the tube, from whence they are reflected backwards, converging to a focus at a small distance before the small mirror; here they form an image from which the rays, proceeding farther backwards, diverge to the surface of the small mirror, from which they are reflected, converging back in their first direction towards the large mirror; but instead of being reflected again from this, they pass through an aperture left in its centre; and before they come to their focus, they are intercepted by a plano-convex lens, by which they are refracted to a focus, where they form an image, from which the rays pass, in a magnifying manner, through a convex eye-glass at the end of the tube, and fall upon the spectator's eye. Thus, whatever be the distance of the object, its image (and this is what is seen) is viewed under the magnifying power of a lens, at but a very short distance from the eye, and presenting the same appearance as though the object was placed at only that distance. The plano-convex lens may be dispensed with, and the image would then be larger, but the field of view would be less.

Acromatic Telescope.—On account of the different refrangibility of the different colours that compose a ray of solar light, it was found impossible to make use of telescopes having great magnifying powers, without at the same time rendering the image formed by the object glass indistinct; for the red rays would be refracted farther from the lens than the blue rays; and if the convexity of the eye-glass is increased so as to magnify the image more, then its aberration would be increased. If the object glass is made less convex, so as not to reduce the image so much by refraction, then its focal

distance would be increased, and the length of the telescope would render it inconvenient: besides, the aperture, through which the rays pass to the object glass, must be lessened in order to prevent those rays from falling on it, which are at too great a distance from its centre to be reflected to the same focus. To remedy these inconveniences the acromatic telescope was invented; which, by using a compound object glass, formed of a double convex of flint-glass, and a double convex of crown glass, prevents any aberration of light; for the aberration produced by one lens, is balanced by the contrary aberration of the other; thus all the rays may be suffered to fall upon the object glass without any contraction of the aperture, and thereby the field of view is considerably enlarged.

Camera Obscura.—This is made by placing a convex lens in a tube, which draws out from one side of a box, at the opposite end of which is placed a plane mirror, inclining upward at an angle of 45 degrees; the top of the box is formed of oiled paper, or of plane glass, so that by looking at it, the images of all objects before the convex lens will be seen in a beautiful manner, and may be traced by a pencil on the outside. If the mirror is inclined downwards at the same angle, the images will be thrown to the bottom of the box, and may be received upon white paper.

Magic Lanthorn.—The construction of this is very simple; it consists of a tin lanthorn, within which is a lamp, whose light passes through a large plano-convex lens placed in a tube fixed in the front; another tube, having in it a small convex lens, is made to slide into the first, and a reflector is usually placed at the back of the lamp; when a small glass, having on it transparent paintings, is inserted, in an inverted position, into an aperture left for the purpose between the lamp and the large lens, a magnified image is thrown upon the opposite wall: the room should be entirely dark.

Phantasmagoria.—In the magic lanthorn the images are seen within a circle of light, but in the phantasmagoria the figures only are light; and all the surrounding surface is dark: this is produced by using glasses, which instead of being white with transparent colours, are painted black, except where the figures are drawn.

Note.—Perspective was named as forming one branch of Optics, but it is impossible to treat of this subject without having drawings and figures to which reference can be made; it has therefore been omitted.